Substorms in Coupled Models:

Expanding Coupling between BATS-R-US and RAM-SCB

D. T. Welling[1] J. Haiducek[1]

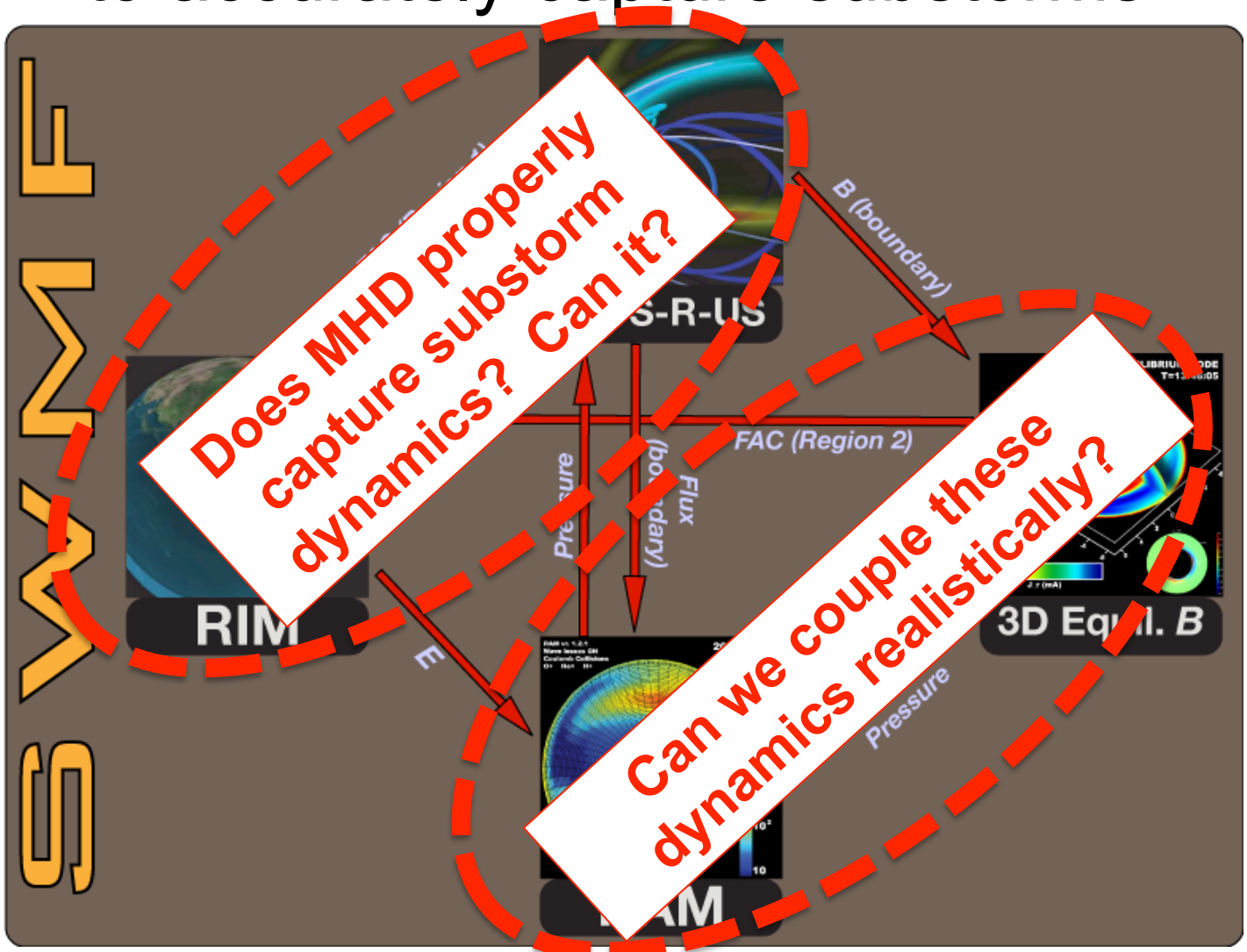
G. Toth[1] V. K. Jordanova[2]

[1]University of Michigan CLaSP Department

[2]Los Alamos National Laboratory

Overview

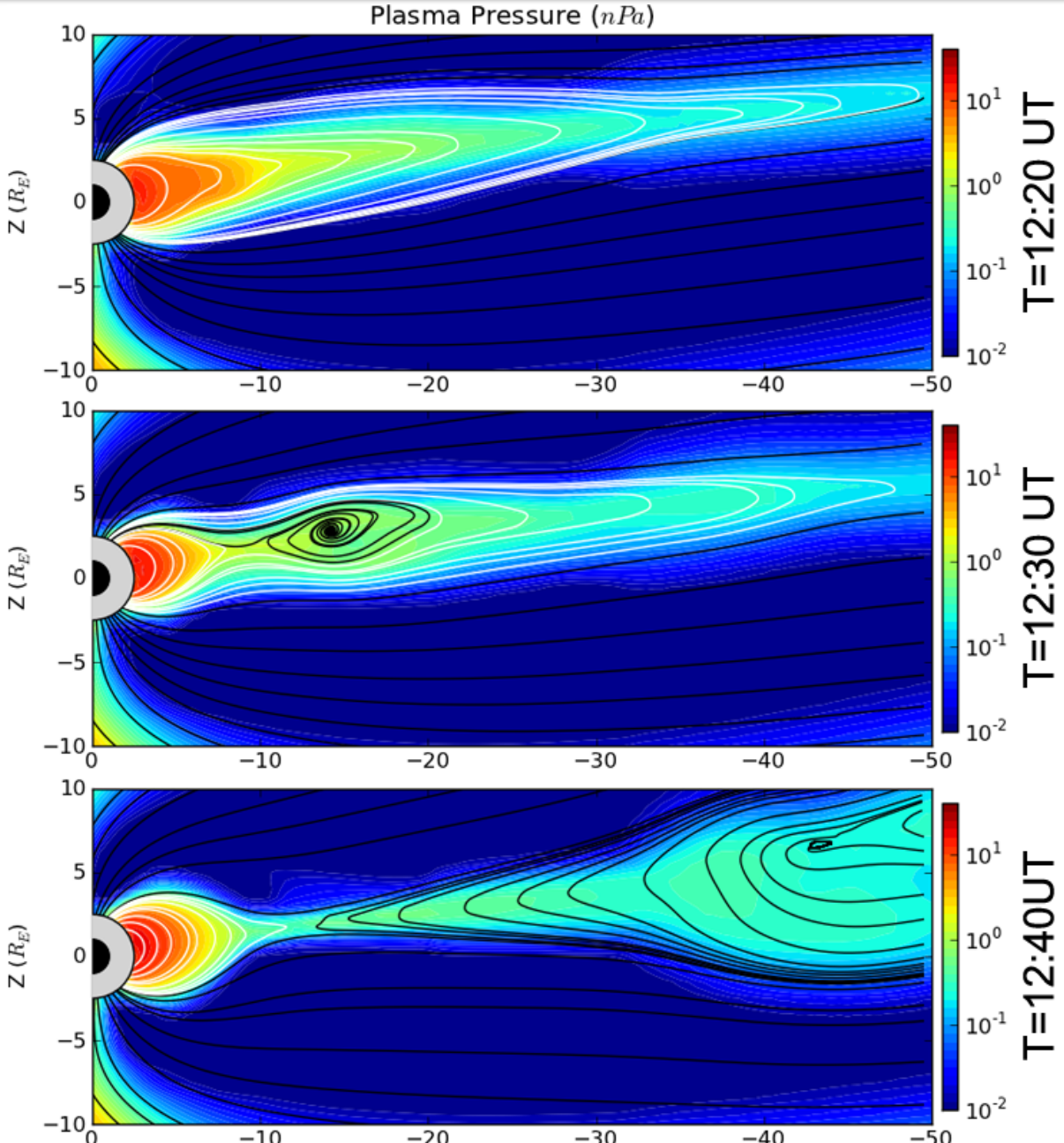
Goal: Used a coupled, multi-scale, global model to accurately capture substorms



Example “Hit”

Success!

- Southward turning.
- No pressure pulse.
- Good timing agreement with GEO observation



Example "Hi

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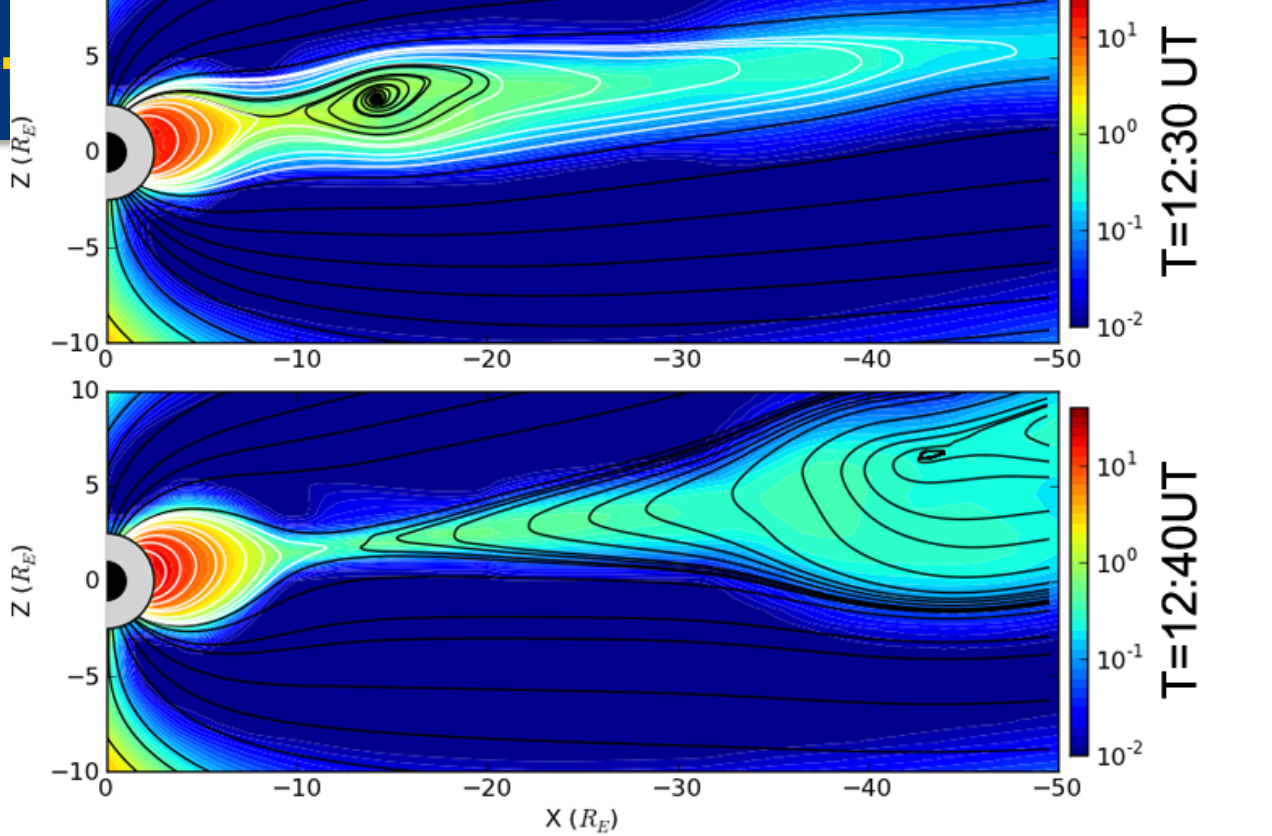
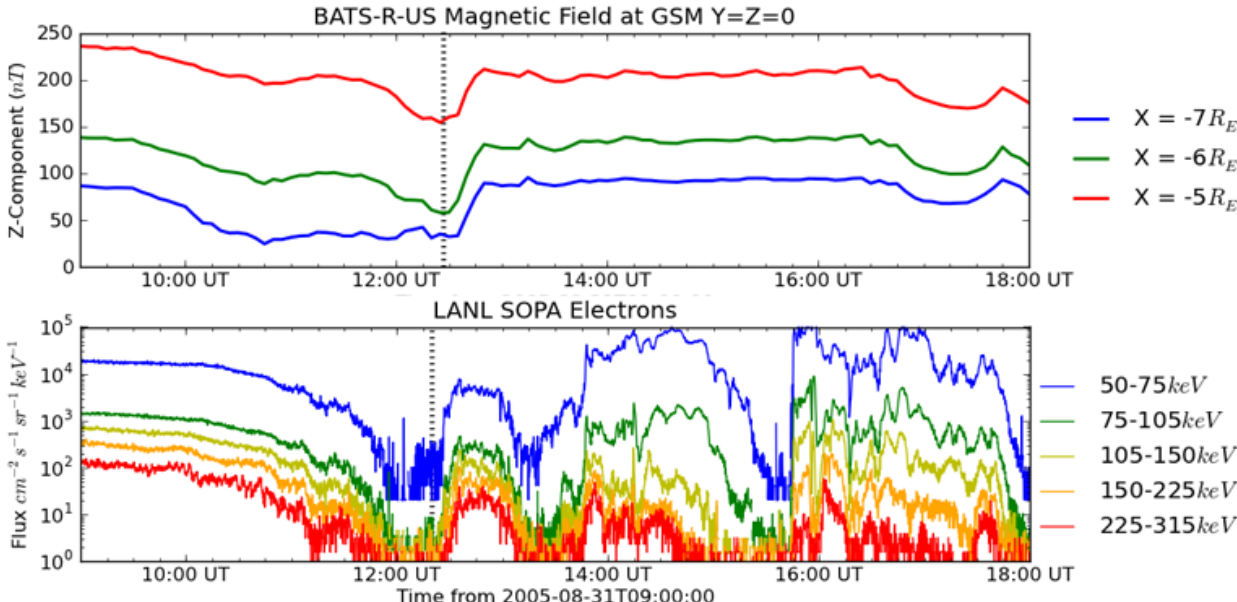
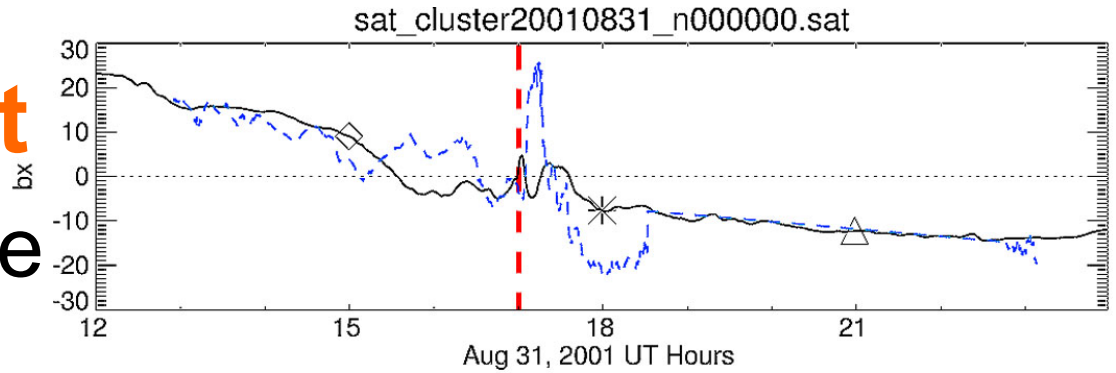


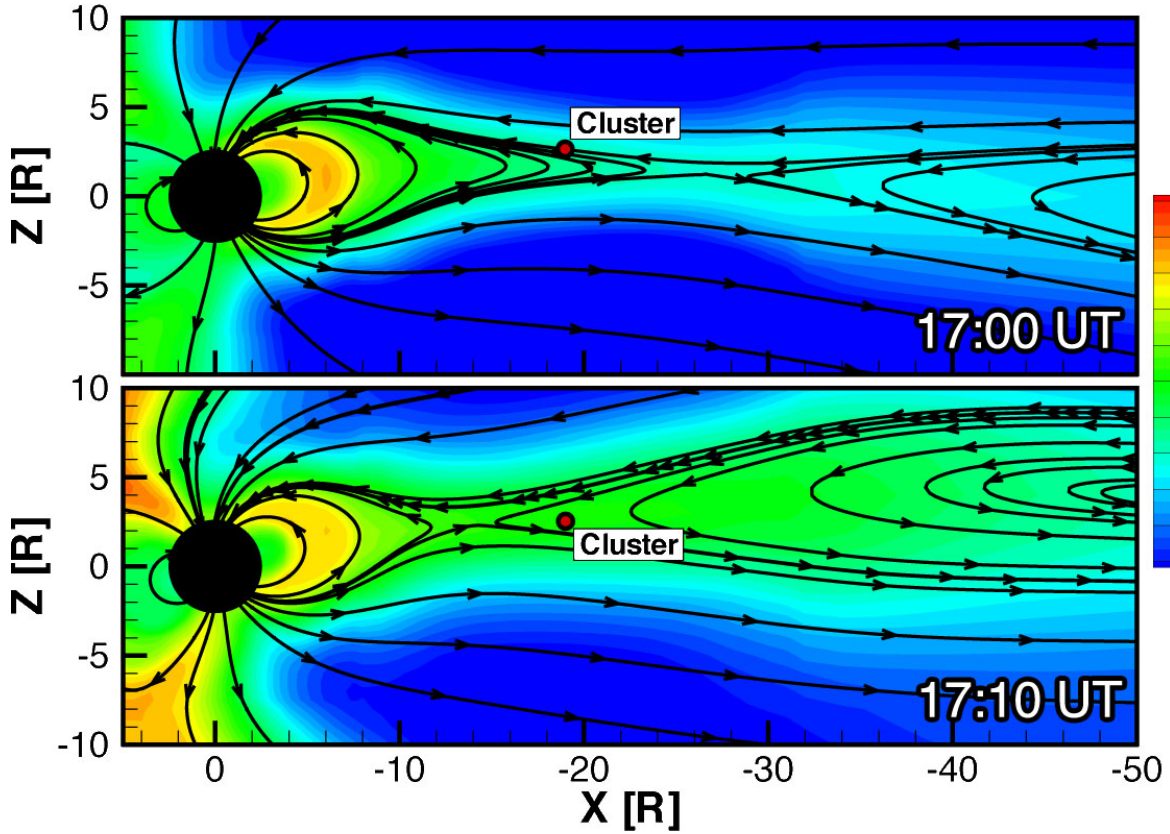


Example "Almost Hit"

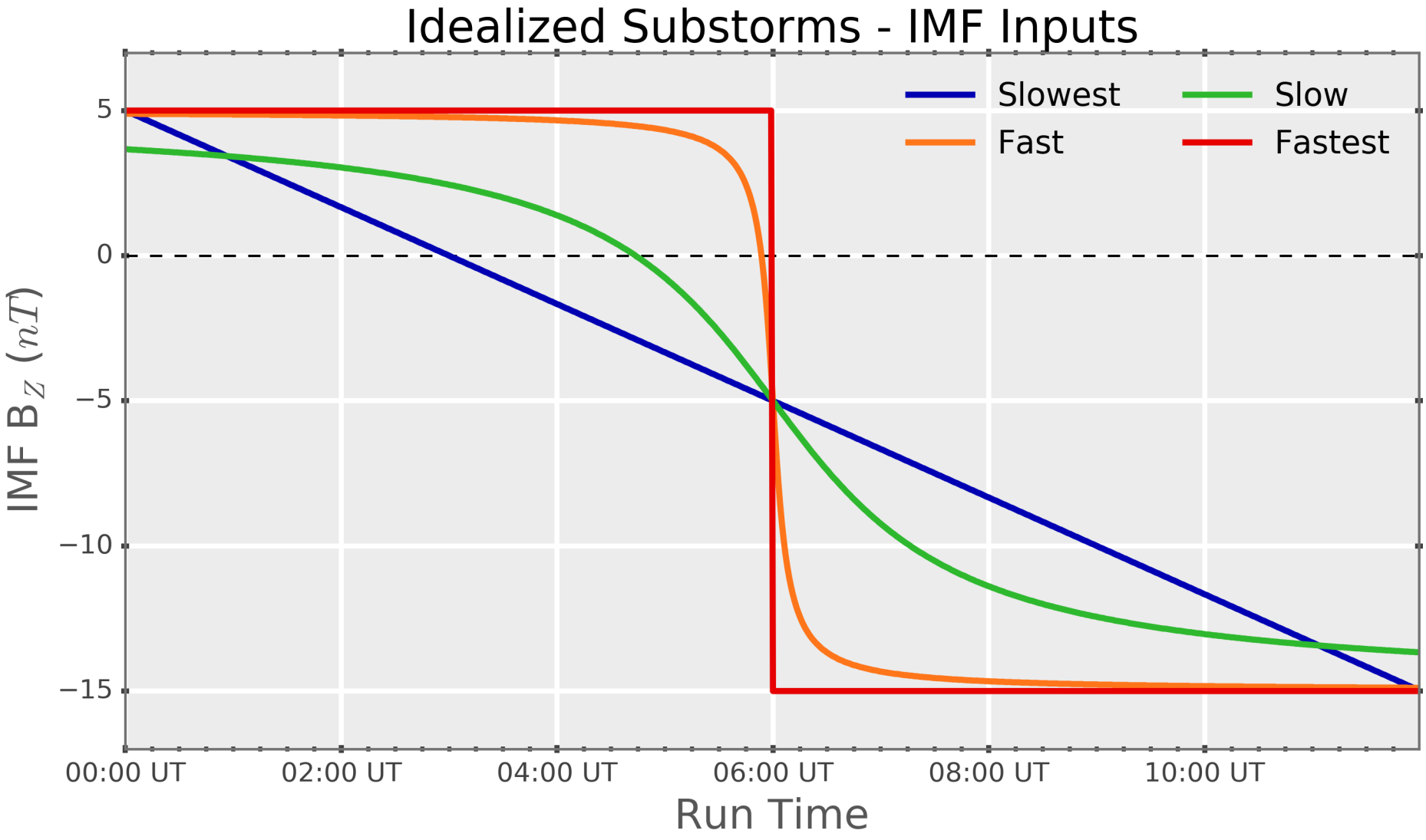
Partial Credit

- Huge pressure pulse.
- Weak, transient southward turning.
- Good timing, poor field geometry.





An Idealized Experiment



Minimal Substorm Model

Rules for simple loading-unloading:

- Solar wind power input at magnetopause P accumulates energy in magnetotail E.

$$\frac{dE}{dt} = P = \varepsilon(v, B)$$

- Unique minimum energy state for magnetosphere F exists for given solar wind state P.

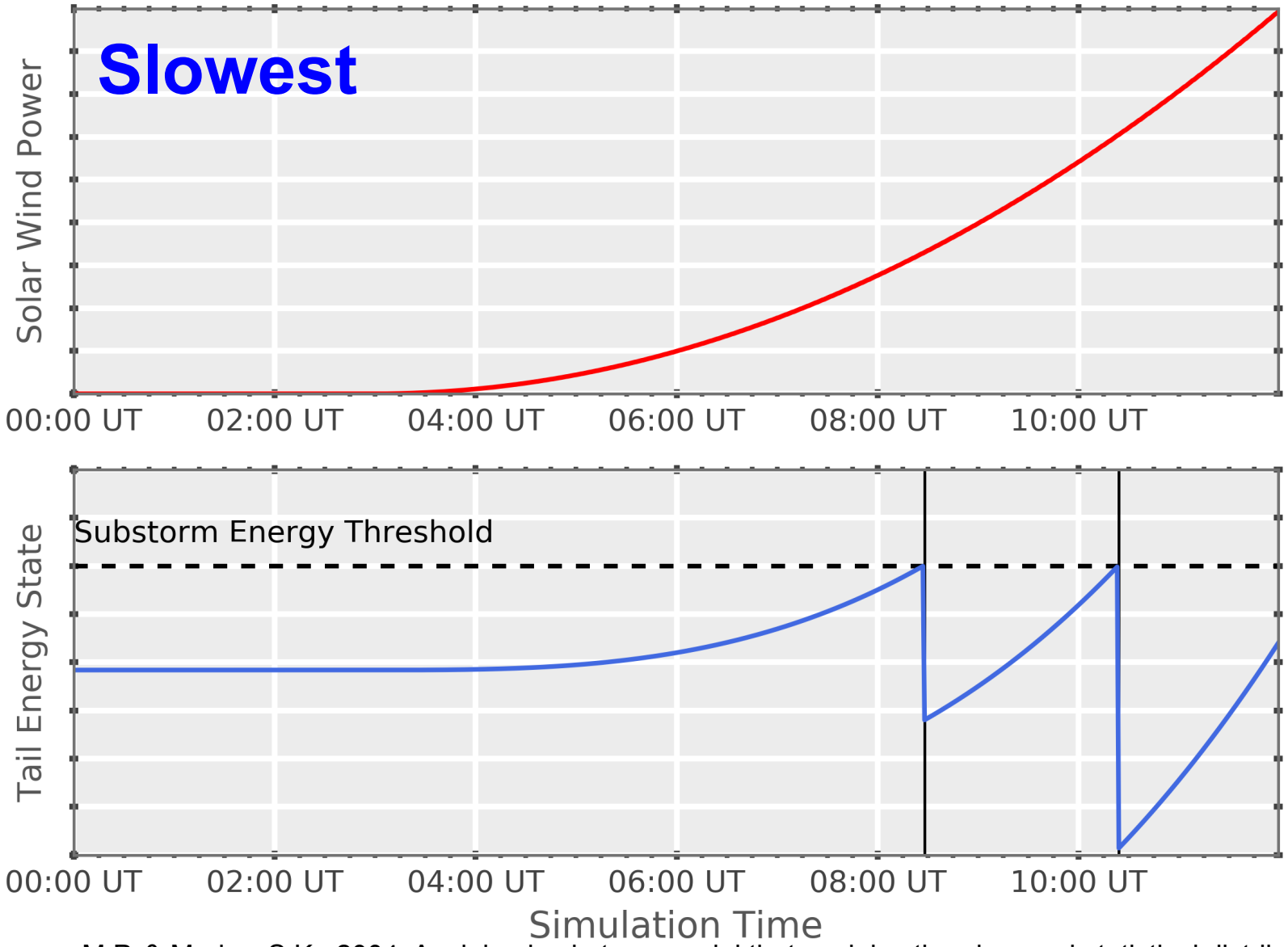
$$F = C - DP$$

- Magnetotail can only move to lower energy state F when energy threshold C is exceeded.

$$E \rightarrow F \quad \text{when} \quad E \geq C$$

- For constant input, substorms occur with constant period of D
  - Expect D = 2.5-3 hr *[Borovsky et al., JGR, 1993; Freeman and Farrugia, JGR, 1995; Huang et al., JGR, 2003]*

Expected Results



Freeman, M.P. & Morley, S.K., 2004. A minimal substorm model that explains the observed statistical distribution of times between substorms. Geophysical Research Letters, 31(12), p.L12807.

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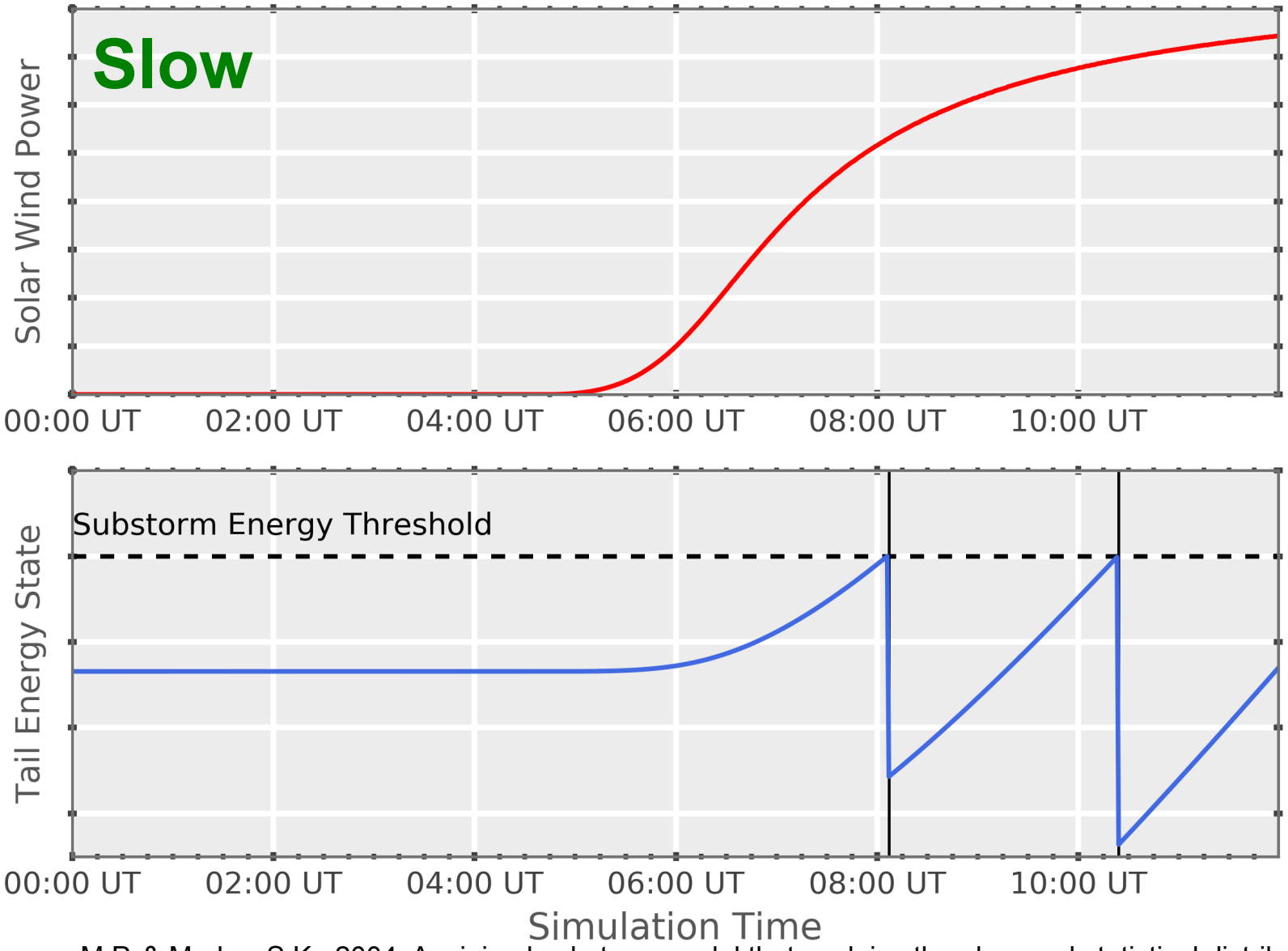

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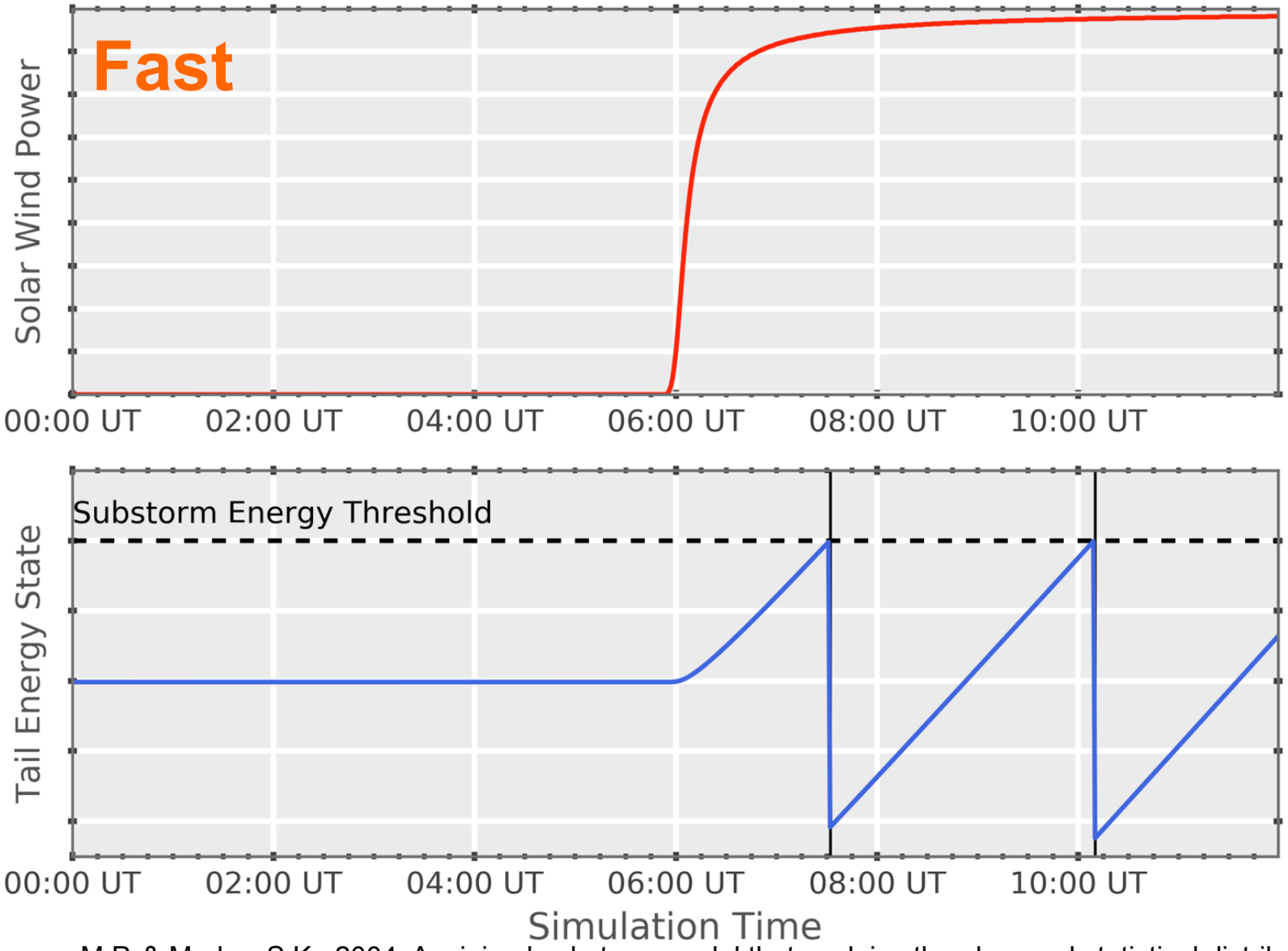

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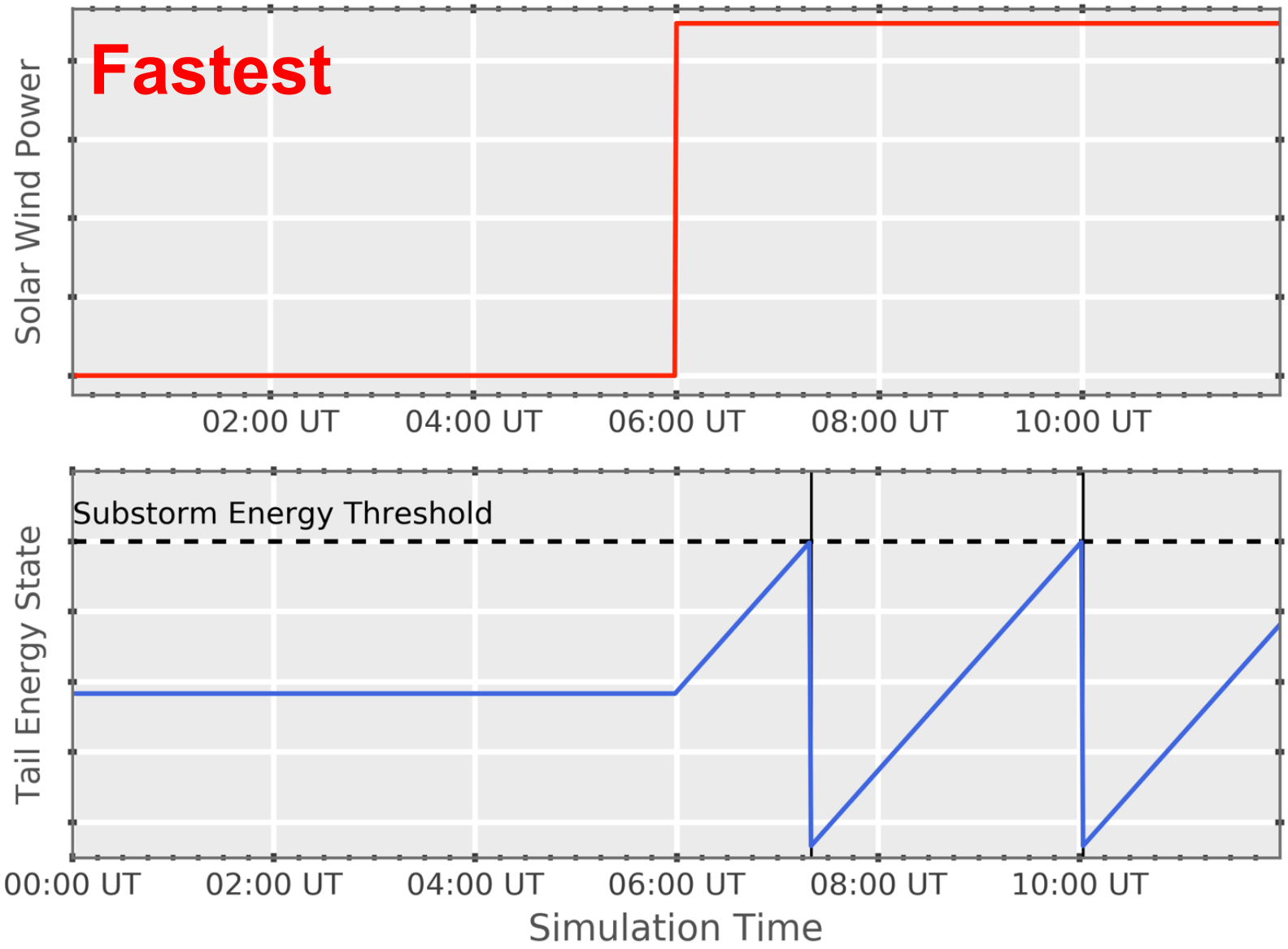

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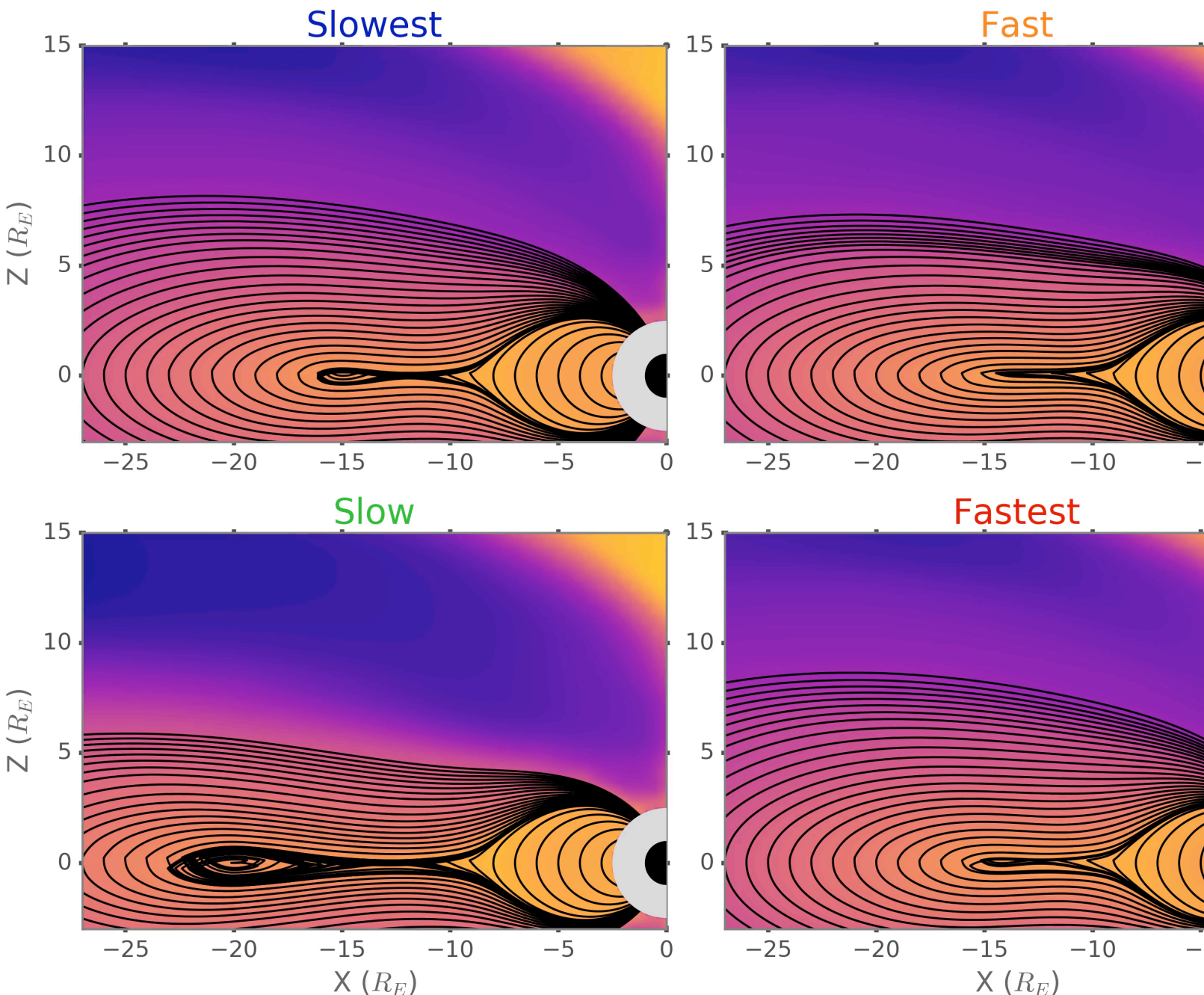
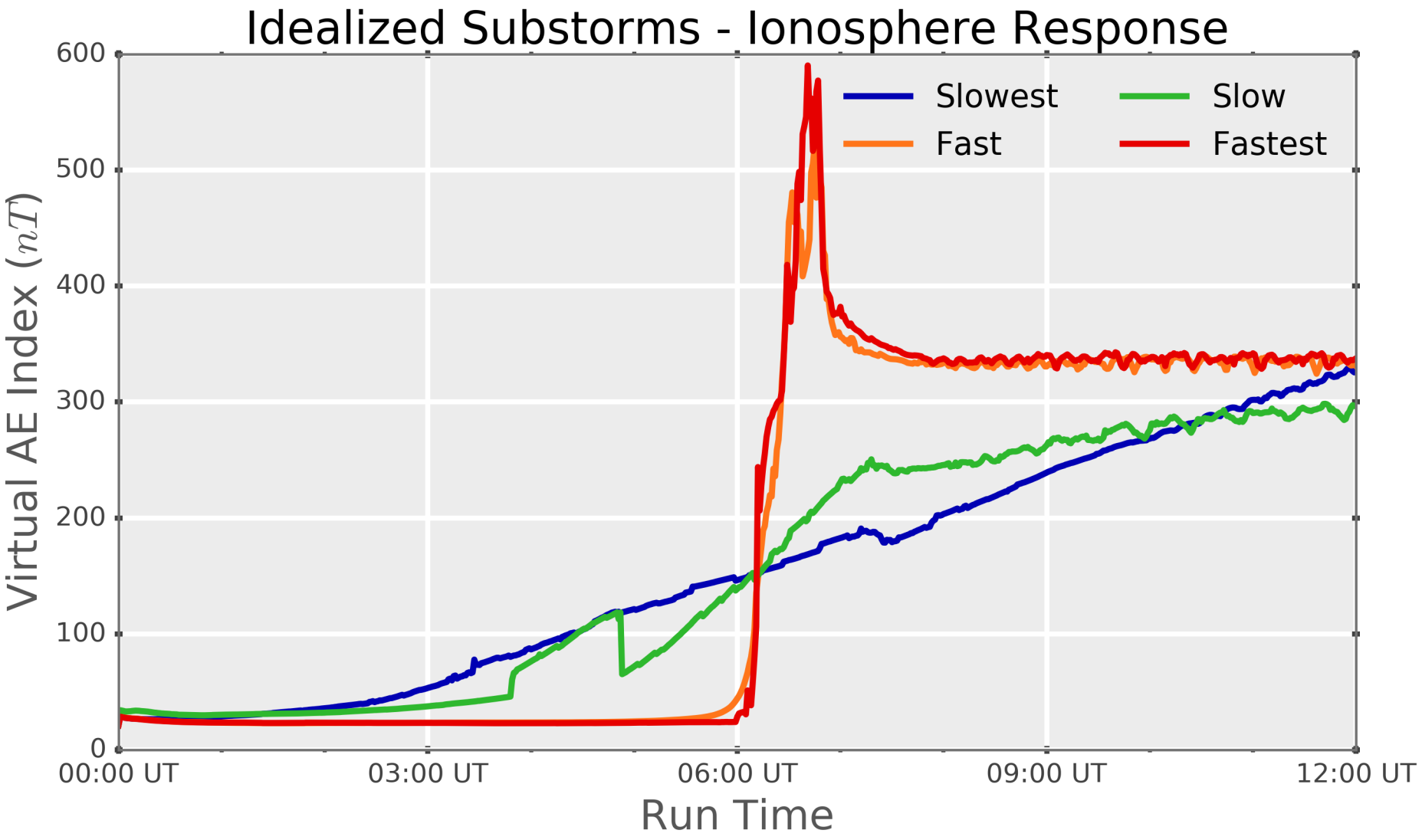
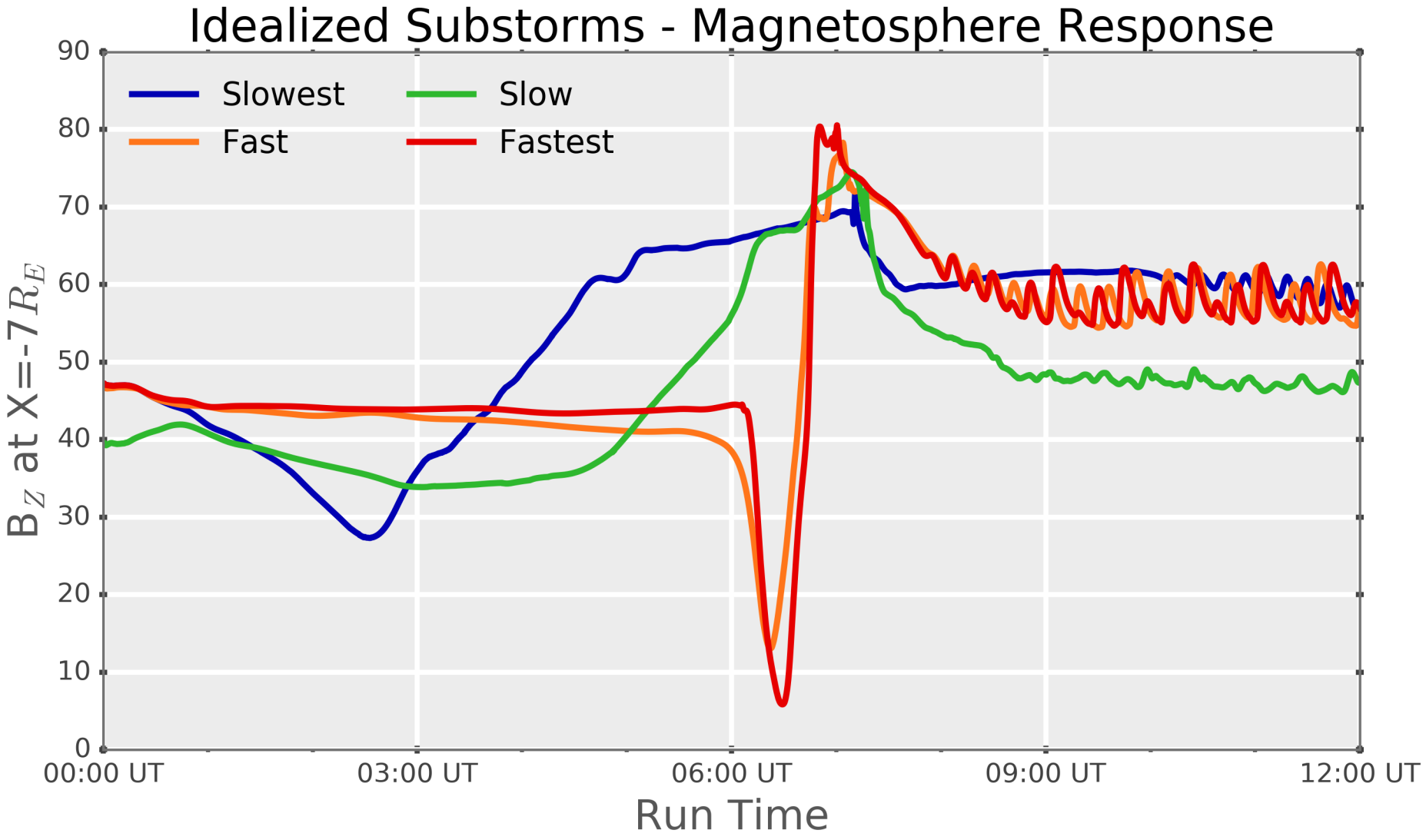
Ideal


Run Time = 01h00m
Slowest
Fast
Slow
Fastest
Z (R_E)
X (R_E)
15
10
5
0
−25
−20
−15
−10
−5
0

Results - Ionosphere



Results - Magnetosphere



Key Questions

Under what conditions can ideal MHD capture substorms?

- System appears to be “leaky”.
- Quick timescale IMF change required.
- What about real world conditions?

How can MHD be extended to improve performance during substorms?

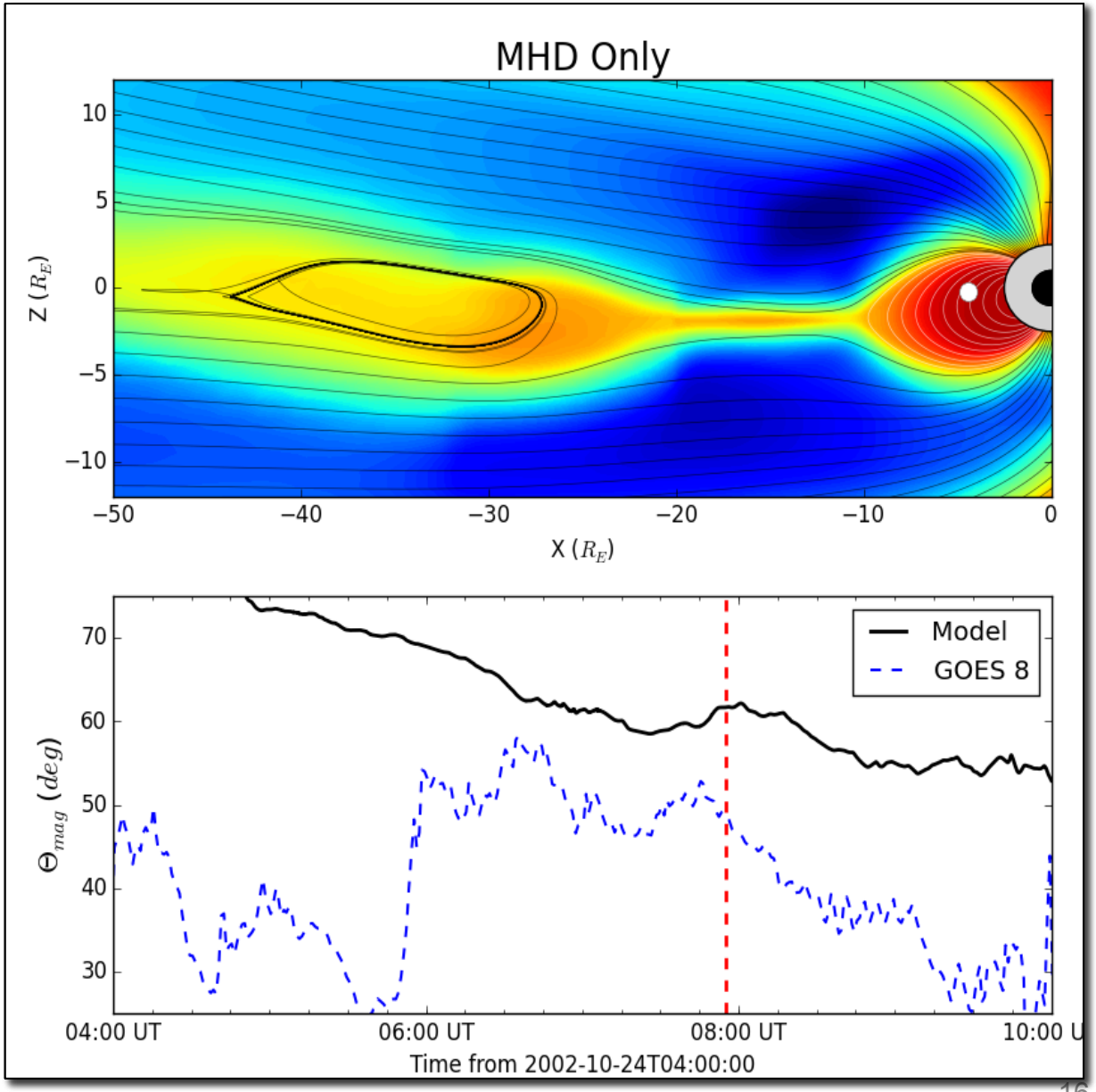
- Resistivity: Anomalous, Hall
- Heavy Ions: multi species/fluid
- Anisotropic MHD
- MHD with embedded Particle-in-cell (EPIC)

Outflow & Substorms

MHD Only:
weak event, terrible timing.

MHD+PWOM:
Stronger event, poor timing.

MHD+GPW:
Excellent comparison.



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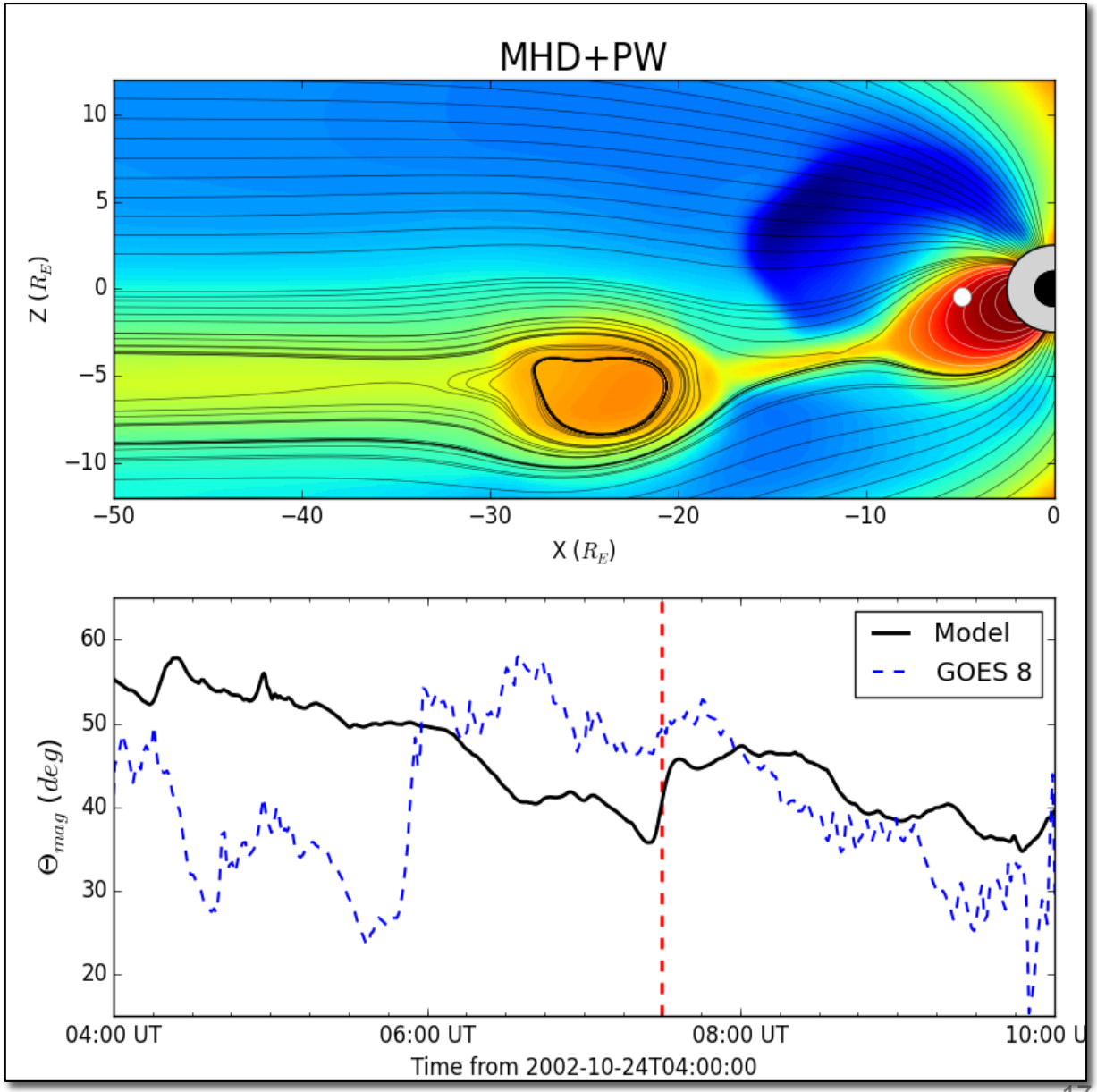

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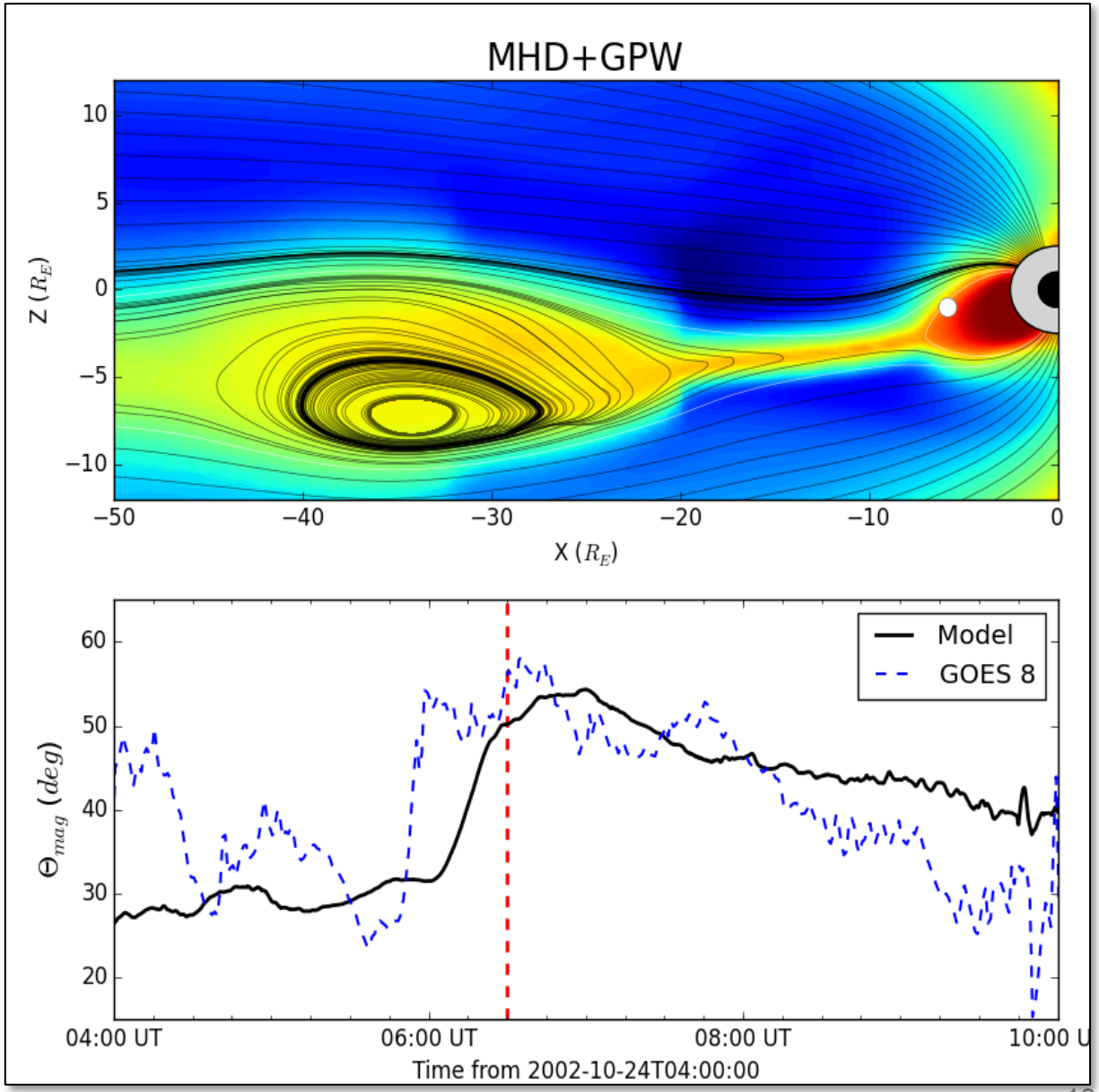
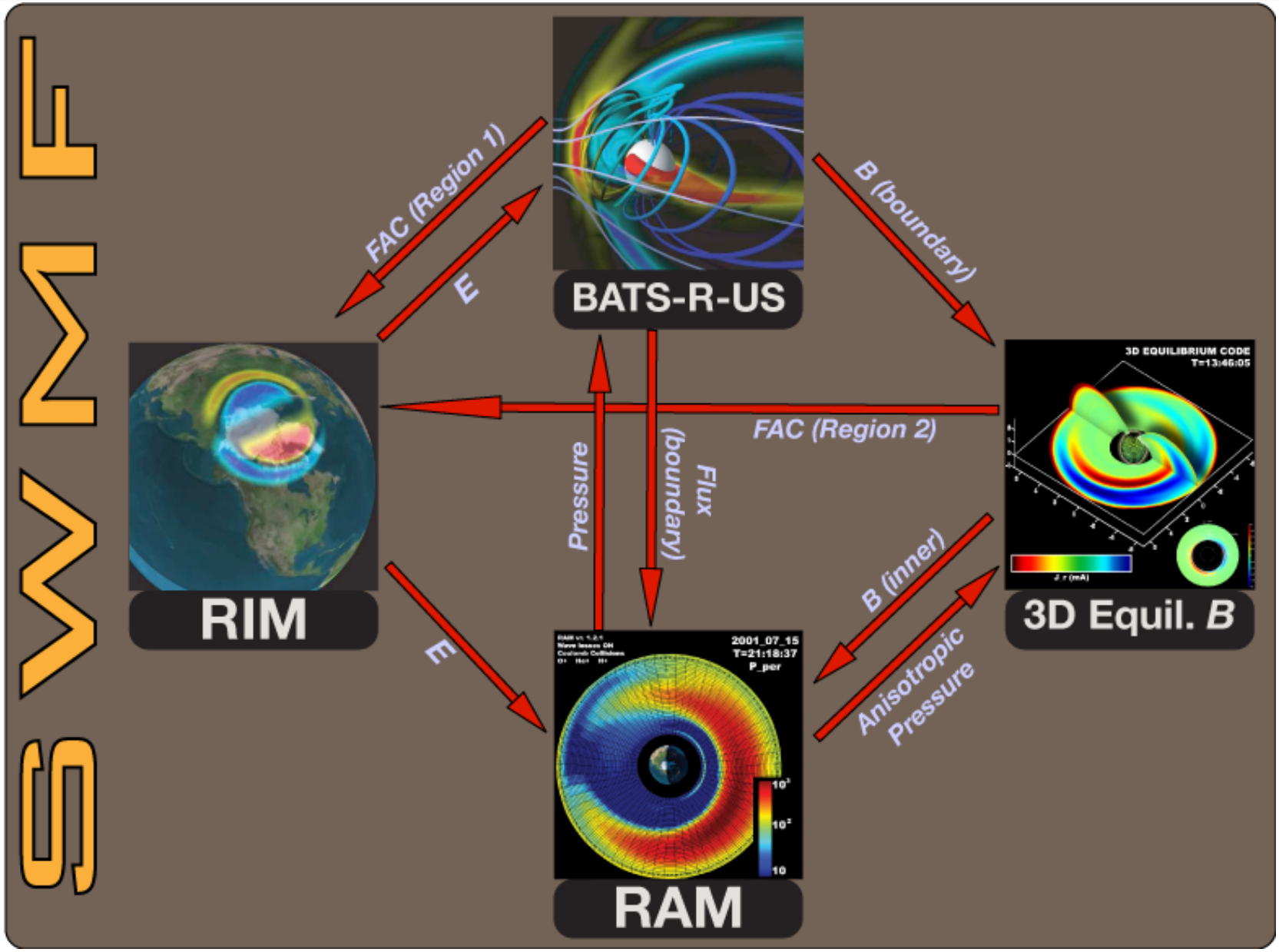
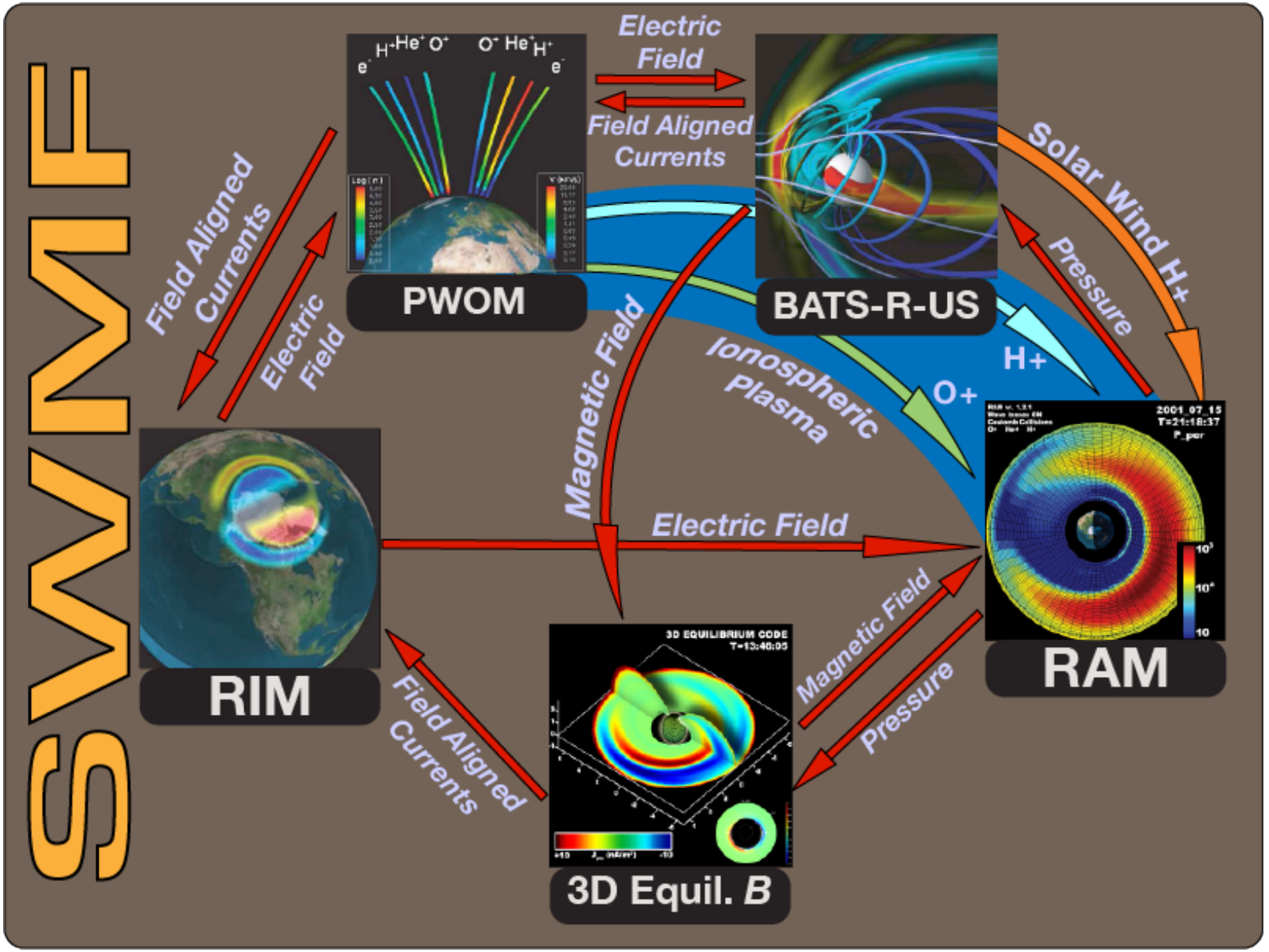


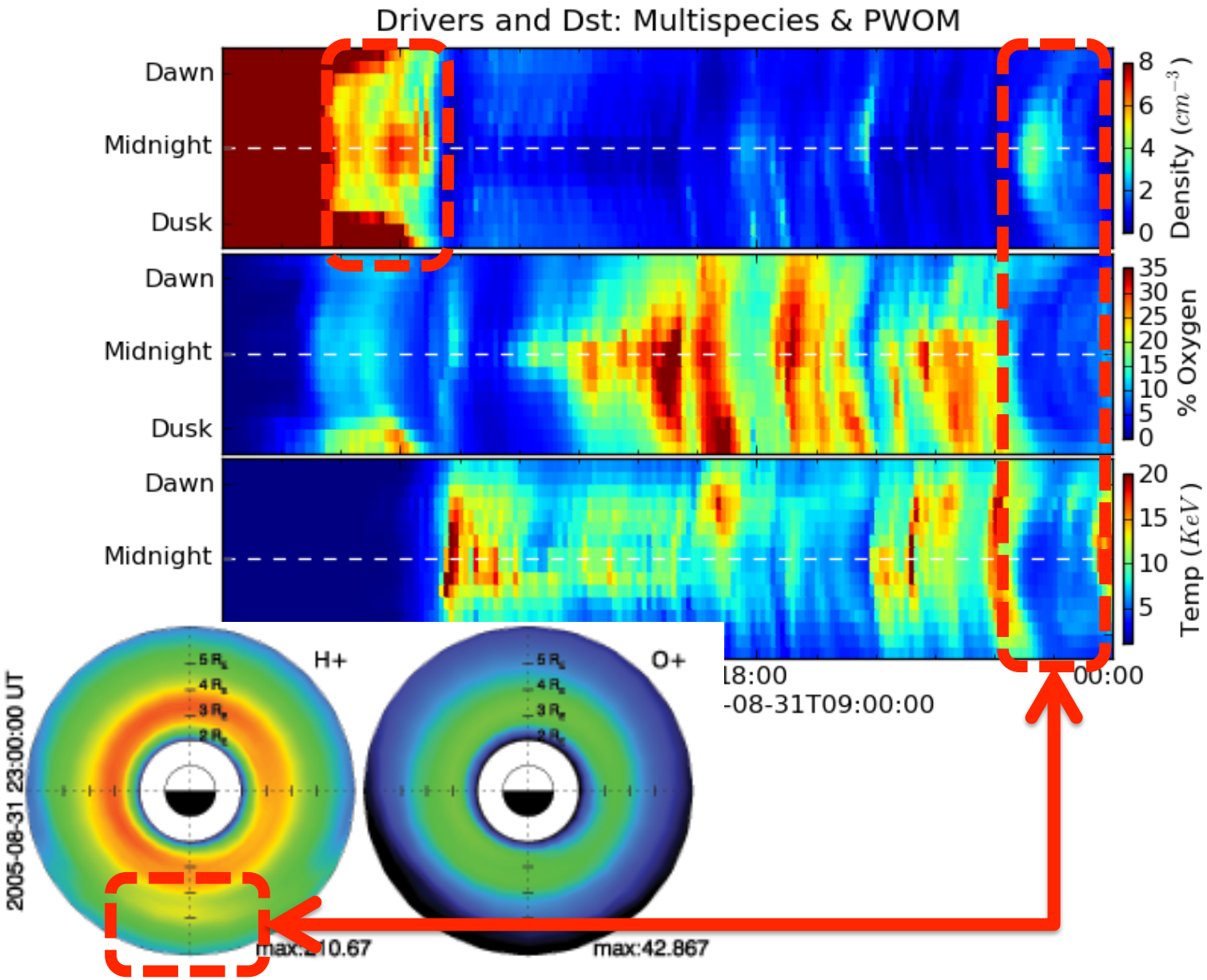
SWMF: GM-IM-IE w/ RAMSCB



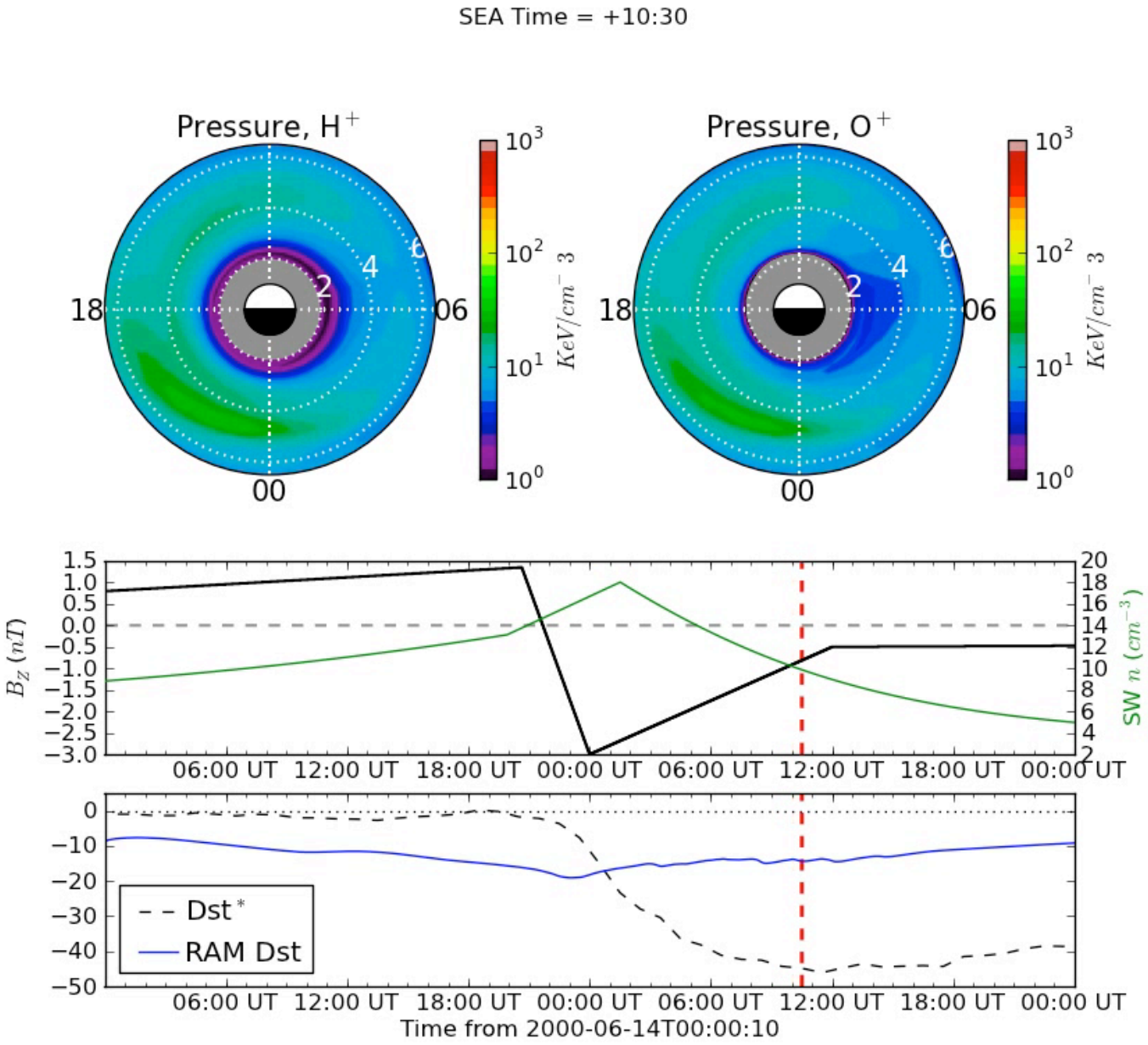
Expanded Earth Coupling



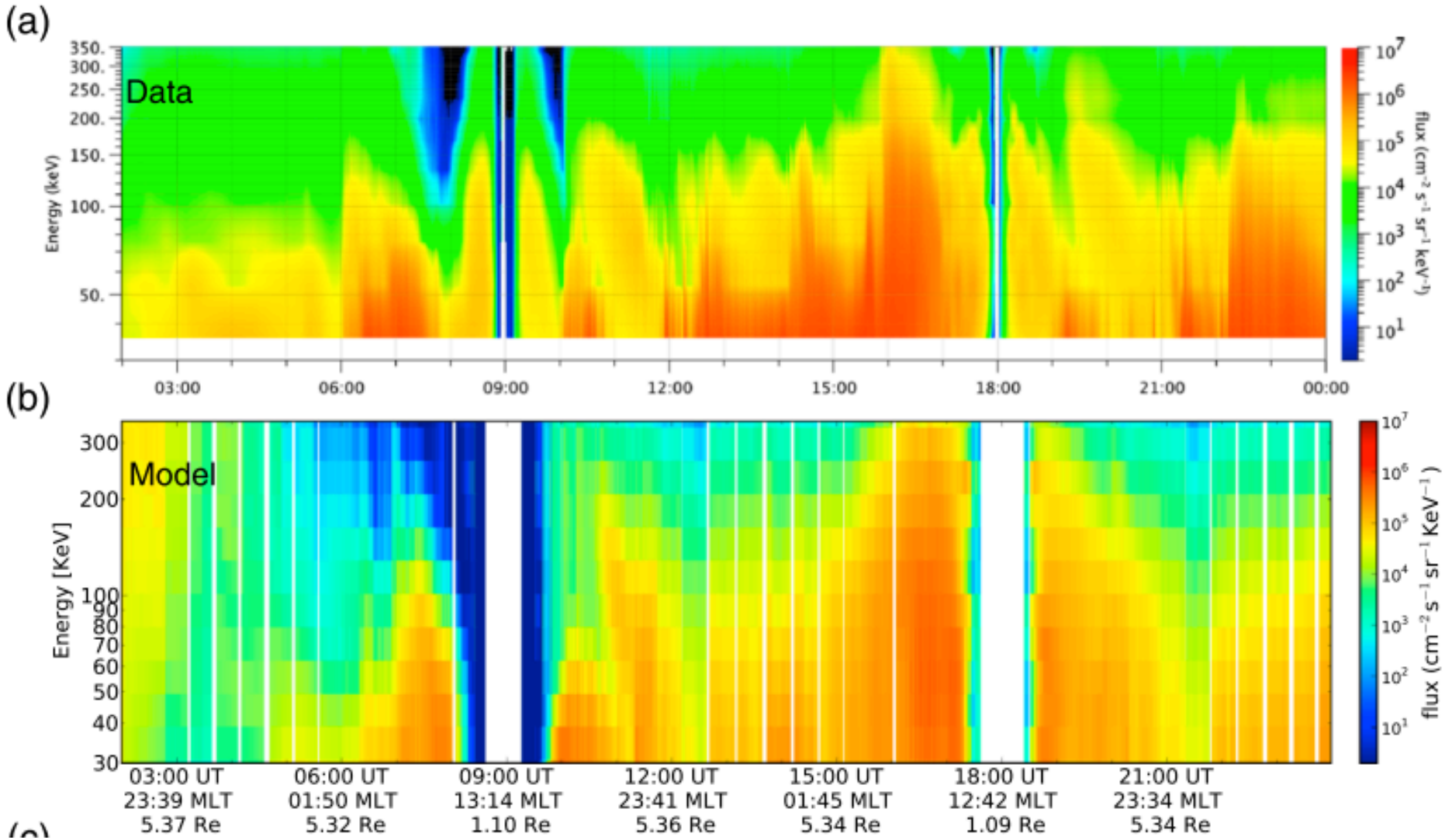
Substorm Injections



Ring Current Injections

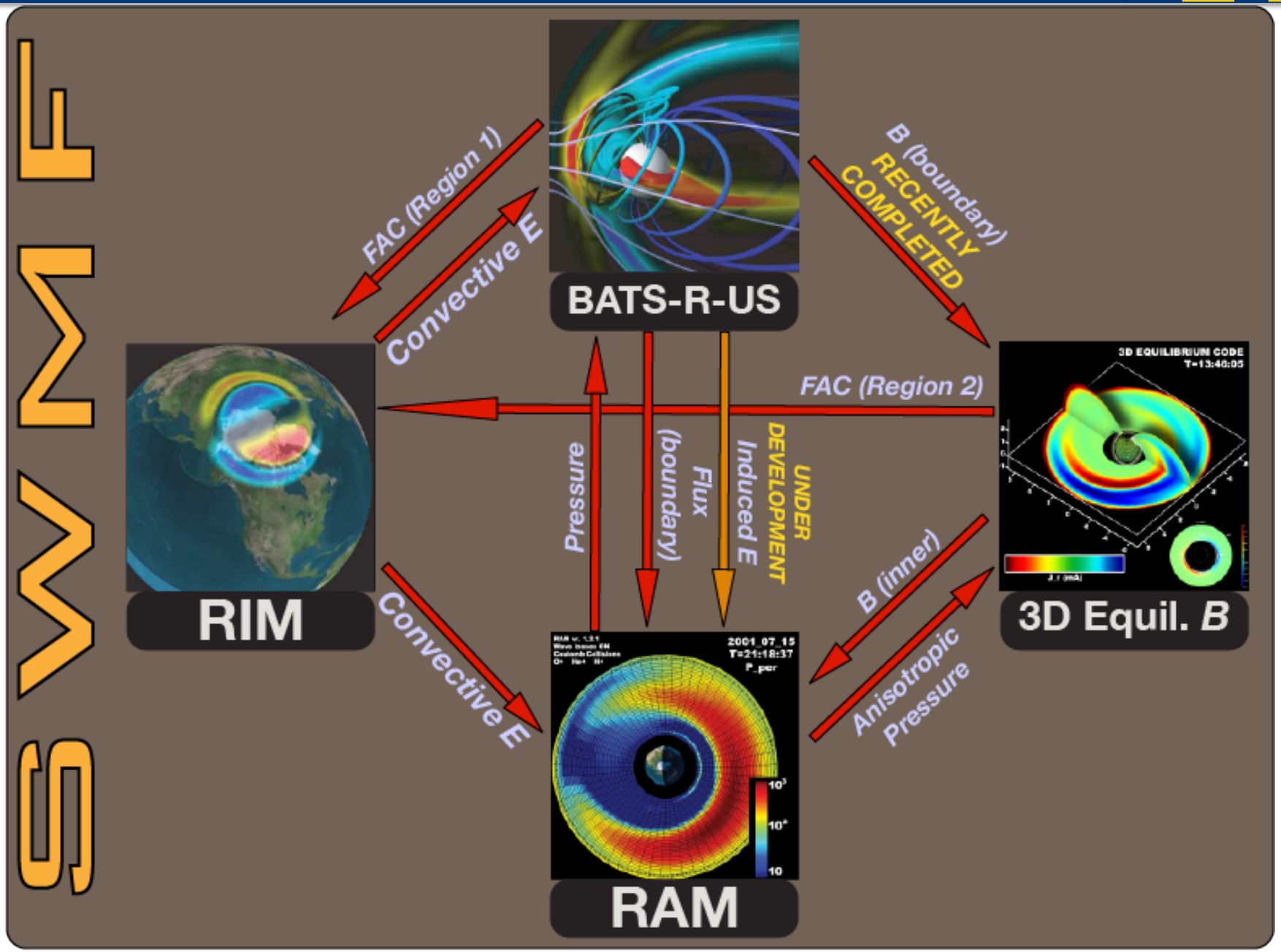


Injections into RAM-SCB

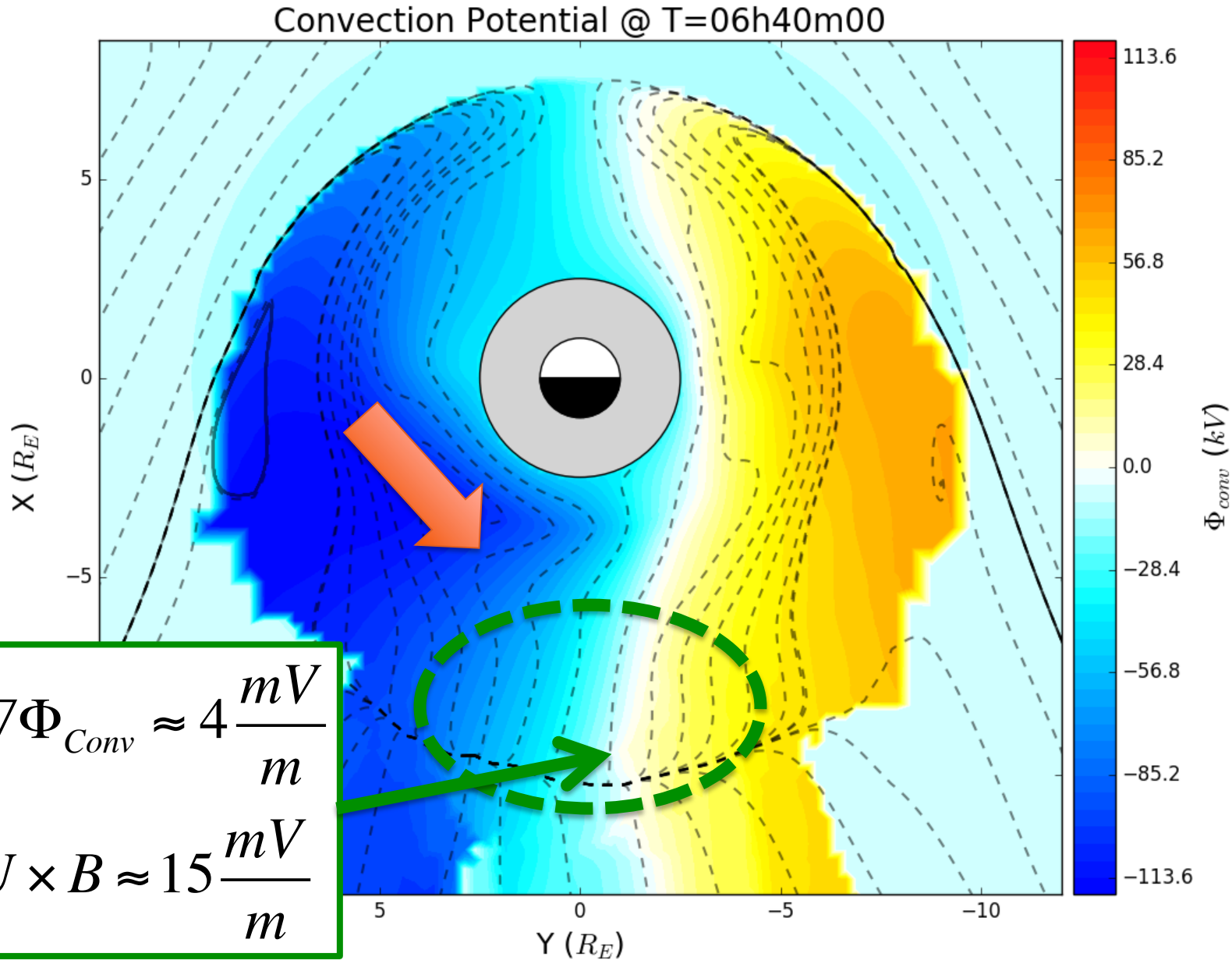


Yu, Y. et al., 2014. The role of ring current particle injections: Global simulations and Van Allen Probes observations during 17 March 2013 storm. Geophysical Research Letters, 41(4), pp.1126–1132.

Induced E-Field Coupling



Potential Field vs. Velocity



$$\nabla\Phi_{Conv} \approx 4\frac{mV}{m}$$

$$U \times B \approx 15\frac{mV}{m}$$

Summary

Ideal MHD can reproduce substorm features

- Quality and reliability still under evaluation.
- Many option to expand MHD and improve MHD performance during substorm events.

Coupling to ring current models allows substorm dynamics to be driven into the inner magnetosphere

- Particle injections, convection field produce qualitatively reasonable results.
- We are expanding coupling to use the whole UxB electric field.